

Spring 2014

ELICITING AND CHARACTERIZING STUDENTS' MENTAL MODELS WITHIN THE CONTEXT OF ENGINEERING DESIGN

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PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Chelsey Dankenbring

Entitled

Eliciting and Characterizing Students' Mental Models within the Context of Engineering Design

For the degree of Master of Science in Education

Is approved by the final examining committee:

Dr. Brenda Capobianco

Dr. Todd Kelley

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To the best of my knowledge and as understood by the student in the *Thesis/Dissertation Agreement, Publication Delay, and Certification/Disclaimer (Graduate School Form 32)*, this thesis/dissertation adheres to the provisions of Purdue University's "Policy on Integrity in Research" and the use of copyrighted material.

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04/22/2014

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ELICITING AND CHARACTERIZING STUDENTS' MENTAL MODELS WITHIN
THE CONTEXT OF ENGINEERING DESIGN

A Thesis

Submitted to the Faculty

of

Purdue University

by

Chelsey Dankenbring

In Partial Fulfillment of the

Requirements for the Degree

of

Masters of Science in Education

May 2014

Purdue University

West Lafayette, Indiana

Dedicated to my mom – your love and support made this possible. Thank you for always
being my biggest fan. I love you bigger than Dumbo.

ACKNOWLEDGEMENTS

Graduate school has been a long journey full of twists, turns, and obstacles to overcome. This has been one of the most difficult, yet most rewarding, times of my life. To say it has been easy would be a lie, but thankfully I had many people in my life to provide encouragement, guidance, and moral support; for that I am forever grateful.

I was blessed to be given the world's greatest mom, and yes I may be biased, but in my eyes it is the truth. Mom, you are the strongest person I know and I thank you for being my rock throughout my entire life. You have always been there for me and believed in me no matter what the situation. Your love, support, advice, and pep talks helped me through the hard times and your smile, hugs, and endless "whoops!" made the good times even better. You are my mom, my confidant, my inspiration and my role model. My biggest goal in life is to be half the mom you are.

I am also lucky enough to have an amazing man to call my dad. Dad, thank you for always being a willing listener and wise advisor; your words of wisdom has taught me how to look at life from various perspectives. Your endless encouragement motivates me to work hard and your kind spirit makes me want to be a better person. I love you bigger than a lake that goes all the way around the world.

Not only has Purdue provided me with a great education, but it also introduced me to the two best friends a girl could ask for. Wenhan Zhu, thank you for knowing me

better than I know myself. With just one look you know exactly what I'm thinking and feeling, and there has been no situation that you could not remedy. You stood by me when I was at my best and at my worst and your friendship got me through some of the hardest days of my life. I admire your thoughtfulness, crazy work ethic, and generosity. I look forward to the next phase of our friendship in the great state of Texas!

Madeline Rupp (a.k.a. Rupp-G), thanks to you I am graduating with most of my sanity still intact and a good bill of health. I can always count on your hilarious one-liners, animated facial expressions, and unrivaled karate skills to brighten my day. You are one of the nicest, caring, considerate, and open-minded people I know. Not once did you throw something at me when I constantly distracted you from your writing, even though I am sure I deserved it. Your keen eye, way with words, hard work, and critical thinking helped me become a better writer and graduate student. Even though our time together is coming to an end, I know with 100% confidence ($p < 0.01$) that we will be BFFs forever. Thank you, Maddie, for always being the Robin to my Batman (Kevin Kaluf, personal communication). I am, yours most sincerely, Chelsey Dankenbring (a.k.a D-bring).

I also want to thank the members of my graduate committee: Dr. Brenda Capobianco, Dr. Dan Shepardson, Dr. David Eichinger, and Dr. Todd Kelley. I am very grateful for the guidance, support, and advice each of you has given me over the past few years. You all have helped me to become a better student, researcher, writer, and person. I have learned many lessons throughout my time at Purdue University, one being that it is easier to learn, grow, and succeed if you have a strong foundation and support group; that is what you all have been to me. Thank you for always having my best interest in mind and helping me find my life's passion.

Last but not least, I would also like to thank the members of the Science Learning through Engineering Design (SLED) research team, especially Dr. Kevin Kaluf, for always being there to bounce ideas off of and to help me whenever I needed it. A special thank you to Chell Nyquist for answering the millions of questions I had over the years; there was never a question you couldn't answer or a problem you couldn't solve. It is safe to say that you made my graduate career a thousand times easier, and for that I am very grateful. Thank you Qiming Huang for doing the statistical analysis presented in this study. Finally, I would like to thank the teachers that made this thesis possible. Your patience and willingness to help the SLED partnership achieve its goals is very much appreciated.

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OVERVIEW

This thesis is a compilation of two chapters written in manuscript format, both of which examine students' science conceptual understandings of different science phenomenon. Draw-and-explain items were created and used alongside semi-structured interviews to obtain a snapshot of students' mental models. Mental models are defined as structural analogs of the scientific phenomenon being represented and consist of individual elements and the relationships that exist between them.

Chapter one outlines the steps taken to create and administer an open-ended draw-and-explain task that will elicit students' conceptions of the cause of the four seasons. Three classrooms completed the assessment item and inductive analysis was used to identify and characterize five different mental models students' possess: 1. movement of the Earth; 2. position of the sun with respect to Earth; 3. Earth pointing towards and away from the sun; 4. sunlight; and 5. miscellaneous. This study illustrated the various alternate conceptions students harbor regarding this phenomenon.

Chapter two examines two groups of students' conceptual understanding of sun-Earth relationships. One group completed an engineering design task as a culminating activity to a science unit, whereas the second group completed traditional learning activities. The mental models of both groups were elicited and characterized, then compared to determine if engineering design impacted student's science learning.

CHAPTER ONE: DEVISING AN APPROACH TO CAPTURE AND CHARACTERIZE ELEMENTARY SCHOOL STUDENTS' MENTAL MODELS

Abstract

Students' harbor various alternative conceptions about scientific phenomenon. These conceptions arise as students interact with the natural world and construct mental models that enable them to make sense of these interactions. Identifying students' conceptions prior to or after instruction allows educators to tailor lessons to the needs of the students. Effective science instruction can assist students in transitioning from alternative conceptions to more scientifically accurate ideas. A draw-and-explain task was created to provide a snapshot of students' mental models of the cause of the seasons. Inductive analysis was used to identify and characterize students' mental models. Results indicated students' held five mental models of the four seasons. Implications suggest that identifying students' mental models may provide predictive and explanatory power for understanding the interaction between students' science conceptual understanding and engineering design.

Introduction

Students enter the science classroom equipped with ideas, or mental models, about how the world works (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg,

1985). These mental models arise as students construct meaning from their everyday interactions with the natural world. Mental models are cognitive structures in the form of structural analogues that correspond to the phenomena it represents with respect to individual elements and relationships that exist between those elements (Johnson-Laird, 1983; Norman, 1983). Unfortunately, oftentimes students' mental models are inconsistent, incomplete, and scientifically inaccurate, yet they remain coherent to the student (Driver et al, 1985; Driver & Easley, 1978). Students are hesitant to abandon incorrect models that have thus far enabled them to make sense of every-day events, even after receiving formal instruction on the scientifically accepted theory (Driver & Oldham, 1986; Duit & Treagust, 1995; Dykstra, Boyle, & Monarch, 1992; McCloskey, 1983).

Mental models are subjective, derived from personal experiences, social interactions and discourse, as well as previous classroom instruction; thus no two people share the same mental model of a given phenomenon (Driver, 1989; Duit, 1991; Glynn & Duit, 1995; Schollum & Osborne, 1985). An important feature of mental models is their adaptability; these cognitive structures are constantly modified as students acquire new information. Thus, the main purpose of a mental model is to explain the phenomenon, and allow people to generate inferences and predictions about the phenomena (Franco & Colinviaux, 2000; Greca & Moreira, 2000). Students use their mental models as a lens to evaluate and interpret new information; therefore, it is imperative that students' mental models progress from a personal model to a more scientific model (Glynn & Duit, 1995).

Students' of various ages and ethnicities harbor a variety of alternate conceptions regarding why the U.S. experiences four different seasons throughout the year (Atwood & Atwood, 1996; Hsu, 2008; Schneps & Sadler, 1988). These conceptions include the following: (a) the distance between the sun and earth throughout the year (Baxter, 1989; Hsu, 2008; Sharp, 1996; Trumper, 2001; Tsai & Cheng, 2005); (b) students' pre-experiences of a phenomena (Baxter, 1989; Hsu, 2008; Küçüközer, Korkusuz, Küçüközer, & Yürümezoğlu, 2009); (c) the Earth's revolution around the sun (Küçüközer et al., 2009; Sharp, 1996); (d) the Earth's tilt (Baxter, 1989; Küçüközer et al., 2009; Sharp, 1996); (e) the Earth's tilt changing as Earth revolves around the sun (Tsai & Chang, 2005); and (f) the Earth's tilt and Earth's revolution around the sun (Trumper, 2001; Tsai & Chang, 2005). Interestingly, results from these studies place emphasis on the conceptions of middle and high school international students. Little is known about elementary school students' conceptions regarding why the U.S. experiences four different seasons. This is of critical importance considering the cause of the four seasons is an elementary school level, disciplinary core idea widely addressed in both the national and state science standards (Next Generation Science Standards Lead States, 2013; Indiana Department of Education, 2011) in the United States. Equally important is designing ways to adequately capture and characterize students' mental models.

Purpose of the Study and Research Questions

The purpose of this study was twofold: 1) to describe the approach used to create draw-and-explain items and 2) to utilize the draw-and-explain tasks to elucidate students' mental models of the cause of the four seasons after completing an engineering design task. This study is guided by the following research questions: (a) what steps are

necessary for developing a draw-and-explain task designed to capture students' mental models of the cause of the four seasons? (b) what mental models do elementary school students possess of sun-earth relationships following the completion of an engineering design task? Although students' mental models were elicited after completing an engineering design task, this study does not examine how engineering design impacted students' mental models or where students' developed these conceptions.

Context of the Study

The context of this study is the Science Learning through Engineering Design (SLED) Partnership. SLED is a multi-year, large scale initiative aimed at improving elementary school students' (grades 3-6) learning of science and math through engineering design. The SLED Partnership includes the participation of over seventy-five elementary school teachers, twenty-five faculty from science, technology, engineering, and education, and local industry partners. To support teachers, SLED pairs Science Technology Engineering and Mathematics (STEM) faculty with practicing teachers in an effort to help teachers mobilize and adapt new curricular resources. The STEM faculty and teachers form a design team which identifies key academic science and mathematics standards that align with the expertise of STEM faculty and the curricular needs of the science teachers. Each design team carefully and critically examines the state academic standards and develops a mutually agreed upon interpretation of each standard. Then the design teams develop, field test, and revise grade appropriate, engineering design-based science lessons. Simultaneously SLED teachers develop standards-based, multi-day implementation plans that outline their instructional goals, objectives, and pedagogical strategies for implementing two tasks each year.

This study is one of several ongoing studies that examine the different ways elementary school students utilize and learn science when engaging in SLED-created engineering design-based tasks. More specifically, this study investigates the process associated with developing an alternative measure for identifying and characterizing students' mental models as they emerge for their engagement in an engineering design task. What follows are a description of the engineering design task the students completed and an overview of the student participants in this study.

Seasons and Shadows Design Task

Each SLED design task is standards-based, classroom-tested, and demonstrates the application of key science concepts in the context of a real world problem. For this study, emphasis is placed on a fifth grade design task that focuses on the concept of the four seasons. More specifically, what causes the four seasons.

This task is presented to students in the form of a design brief. According to Capobianco, Nyquist, and Tyrie. (2013) a design brief is:

a plausible scenario or situation in which students are asked to solve a problem using the engineering design process...Embedded in a design brief is a description of the context of the problem that includes a targeted end user, a client who needs help, a description of the problem that needs to be addressed, and a list of requirements for the design. (p. 61).

The design brief for the Seasons and Shadows task instructs students to design a structure that will shade a picnic table located at specific latitudes at lunchtime throughout the entire year (See Appendix A). Students then work in small teams and use their knowledge of seasons, sun angles, and shadows to design the shading structure.

Design constraints include the following: (a) the picnic table and benches are shaded at noon but allow for some sunlight during the early morning and evening hours; (b) the structure is a minimum of 2 meters tall; (c) the cost of the structure is low (a list of materials and their cost is provided); and (d) the structure must be able to stand on its own. To complete this task, students need to understand the position of the sun in the sky, sun angles, the earth's tilt, and how the different seasons affect the sun's trajectory across the sky throughout the day.

Study Participants

During the 2012-2013 academic school year, seventeen STEM teachers from seven different schools participated in the SLED Partnership. A total of 606 students participated across these respective classrooms. A sample of fifty-eight students was purposefully selected from the population. These students completed the Seasons and Shadows design task as a culminating activity to an Earth Science unit about sun-Earth relationships. Forty students were from two classrooms at a rural intermediate school and eighteen students from one classroom at an urban intermediate school located in the central Midwest. Table 1 illustrates that approximately 60% of the participants were male and 40% were female and approximately 66% of the participants were Caucasian and 24% were Hispanic.

Table 1

<i>Demographics of Student Participants</i>							
School	Number of Students	Gender Male	Female	Ethnicity Caucasian	African American	Hispanic	Other
Rural	40	52.6%	47.4%	47.4%	0%	26.3%	26.3%

Urban	19	62.5%	37.5%	75%	2.5%	22.5%	-
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Data Collection

There are two distinct phases in the data collection. The first phase involves the development of the draw-and-explain measure. The second phase entails the pilot testing of the measure to provide another layer of content and construct validity. What follows is a description of the two phases.

Phase One: Development of the draw-and-explain measure

To elicit students' mental models, an open-response item was chosen because "open-ended questions often reveal more information about student understanding than 'traditional' testing methods" (Freedman, 1994, p.3). Specifically, the draw-and-explain technique was chosen primarily because drawings can provide a visual snapshot of a student's mental model that includes information that may be omitted when other techniques are used. The accompanying written description of the drawing allows students to explain and further elaborate on their drawing, which helps the researcher understand students' ideas (White & Gunstone, 1992; Glynn & Duit, 1995). This type of assessment item also enables students who have difficulty expressing their thoughts verbally or through extensive writing, the ability to communicate their ideas and thereby making information that may otherwise be inaccessible available to educators (Rennie & Jarvis, 1995).

Drawings and interviews, often coupled together, have allowed educators to better understand student conceptions related to physical science (Arnold, Sarge, & Worrall, 1995; Benson, Wittrock, & Baur, 1993; Chiras & Valanides, 2008; Vosniadou & Brewer, 1992), life science (Bowker, 2007; Köse, 2008; Reiss & Tunnicliffe, 2001; Shepardson,

1997; Shepardson, 2002; Strommen, 1995), and environmental science topics (Barraza, 1999; Bonnett & Williams, 1998; Shepardson, Wee, Priddy, & Harbor, 2007). Therefore, the draw-and-explain method has been found to be a valid item for eliciting students' ideas on a wide range of topics including astronomy related ideas. Furthermore, this technique has been used to compare the ideas of students from various countries (Barazza, 1999; Reiss et al, 2002; Vosniadou, 1994), across a wide range of age groups (Benson et al., 1999; Köse, 2008; Shepardson, 2002), and a variety of instructional contexts (Bowker, 2007; Christidou et al., 2009; Shepardson, 1998). To capture the mental models residing in the minds of elementary school students, a draw and explain item was administered and semi-structured interviews were used to confirm students' mental models.

The draw-and-explain item used in this study was created by following the steps outlined by Lund and Kirk (2010). The first step entailed identifying the knowledge that will be assessed by the item. To do this, the science content standards, lesson objectives, and science concepts/vocabulary embedded in the Seasons and Shadows design task was reviewed. The science content standards included the following:

1. Science 5.2.2: Observe and use pictures to record how the sun appears to move across the sky in the same general way every day but rises and sets in different places as the seasons change and
2. Science 5.2.3: In monthly intervals, observe and draw the length and direction of shadows cast by the sun at several chosen times during the day. Use the recorded data as evidence to explain how those shadows were affected by the relative position of the earth and sun ([State] Department of Education, 2011).

The lesson objectives included the following: (a) Students will be able to explain the tilt, orbit, shape and motions of the Earth (rotation and revolution) and their relationship to the reasons for the seasons and variable heating of the Earth; (b) Students will be able to describe the variations in the length of day throughout the year by graphing the length of day (from sunset to sunrise) for different latitudes; and (c) Students will be able to design a prototype shade for a picnic table to maximize shade throughout the year given a scale diagram and specific dimensions. The key science concepts were the cause of the seasons (Earth's tilt and revolution around the sun), the locations of the sun in the sky throughout the day, sun angles, and how these concepts affect an object's shadow.

Next, the "big idea" addressed in the design task was deconstructed into small components in order to identify possible topics that students could be tested over. In the case of the Seasons and Shadows task, the big idea was the cause of the seasons. The smaller components were identified as Earth's tilt, Earth's revolution around the sun, and seasonal variations depending on the latitude, how the sun's rays hit areas of Earth during the different seasons, and how the position of the sun in the sky impacts the shadow of an object.

Lund and Kirk (2010) emphasize that the prompt of an open-response item be couched within a real-world context and specify the task students are to do on the assessment item. For this study, the context was the cause of the four seasons and the task entailed drawing a picture and writing and accompanying explanation of their understandings. Before creating the prompt, existing assessment items from elementary science textbooks and the Indiana statewide testing bank (Indiana Department of

Education, 2013; National Center for Education Statistics, n.d.) were examined to identify age-appropriate content, wording, and syntax of assessment items. Similarly, mental models literature was reviewed to determine the format of a validated draw-and-explain item.

The prompt for the draw-and-explain item used in this study was modeled after Shepardson, Wee, Priddy, and Harbor (2007). Specifically, the prompt stated: “In the space below, please draw a picture that shows why the United States experiences four different seasons. Label the different parts of your picture,” and students were provided with sufficient space to draw a detailed picture. A limitation of drawings is that students may struggle to adequately portray their thoughts on paper. Therefore, students were also given another prompt: “Please write a few sentences explaining how your picture shows why the United States experiences four seasons,” as an additional medium of expressing themselves (Alerby, 2000).

The draw-and-explain item was then reviewed by members of the SLED research team, SLED faculty, and fifth grade science teachers for both content and construct validity. After several rounds of feedback and subsequent revisions, the research team finalized the draw-and-explain item that was then piloted in three science classrooms.

Phase Two: Pilot testing and administration of the measure

The final version of the draw-and-explain item was administered orally to three fifth grade classrooms ($n = 59$ students). Students completed the draw-and-explain item in their science classroom after completing the Seasons and Shadows design task. Students were able to take as much time as necessary to complete the item. Once students completed the prompt, the teacher selected two or three students (10% of the sample) to

be interviewed. These students were purposefully selected based on the following criteria: (a) the student (and his/her guardian) completed the required consent documents; (b) the student could articulate his/her ideas clearly; and (c) the student was willing to be interviewed. During the interview, each student was asked to explain his/her drawing. Then each student was given physical models representing the sun and earth and asked to think out loud while physically manipulating the materials to demonstrate why the Earth experiences four seasons. The sole purpose of these interviews was to confirm students' mental models as identified by the draw-and-explain item.

Data Analysis

Students' responses were analyzed at the item level and model level (Vosniadou & Brewer, 1992). At the item level, the individual components of a drawing and accompanying explanation were catalogued and the frequency was determined. At the model level, inductive analysis was used to identify common codes that developed into central themes among students' ideas (Lincoln & Guba, 1985).

In the first round of coding science ideas expressed in students' drawings or written explanations of the draw-and-explain task were documented for each student. This information served as initial codes. Examples of initial codes included the tilt of the earth, revolution, and amount of light Earth receives from the sun.

After completing the second review of the data, initial codes were expanded to include more detailed codes. It should be noted that although initial codes guided the second round of coding, new codes that arose throughout the coding process were added. During the third round of coding, students' drawings and written explanations were coded using the expanded code list. During the last round of coding, a final list or coding

scheme was determined and later used to analyze students' drawings and written responses. Inter-rater reliability (>85%) was determined before proceeding to mental model classification.

Multiple rounds of coding enabled the research team to better understand the conceptions of each student. Identifying overarching mental models based on patterns of codes became problematic. This was the case primarily due to accessory codes, or ideas mentioned in students' responses that were not central to his/her mental model. For instance, a student may have mentioned the word "rotation," but his/her picture and written response highlighted the idea of the proximity of the northern hemisphere to the sun due to Earth's tilt and revolution around the sun. Therefore, to ensure each student's response was categorized in the appropriate mental model, each response was reviewed and the "big idea" extracted. After all big ideas were listed they were collapsed into five mental model categories

Table 2

<i>Description of Students' Mental Models</i>	
Classification	Description
Movement of the Earth	Earth's rotation about its axis and/or Earth's revolution around the sun is the cause of the four seasons
Position of the sun with respect to Earth	The position of the sun, either close/far or high/low, with respect to Earth is the cause of the four seasons
Earth pointing towards and away from the sun	The northern hemisphere pointing towards and then away from the sun throughout the year is the cause of the four seasons
Sunlight	Various aspects of sunlight is the cause of the four seasons
Miscellaneous	Drawings include non-scientific ideas or ideas that do not fit within one of the four other mental models

Next, individual drawings with accompanying explanations were independently categorized as representing a particular mental model. To add a level of specificity to each broad mental model, subcategories were formed within each mental model category based upon repeating themes present within each category. Individual student responses were then categorized into each subcategory by two independent researchers. Inter-rater reliability (>90%) was determined.

Results and Discussion

As mental models consist of individual elements, or ideas, and the relationships between them, student responses were analyzed at both the item level and the model level. Item level analysis identified seven topics that students considered relevant and important to the cause of the four seasons. Model level analysis examined the relationships that existed between the individual items identified in the item level analysis.

Item Level

At the item level, items present in students' responses as well as their frequency are presented in Table 3.

Table 3

Overall Percentage (%) of Items in Students' Draw-and-Explain Responses

	Movement	Distance	Sunlight	To/Away	Miscellaneous	Overall
Earth	100	100	100	100	63	97
Sun	81	100	100	91	63	90
Axis	75	31	55	82	50	66
Revolution	63	8	73	45	13	44
Rotation	56	15	55	45	25	41
Tilt	31	23	55	100	38	40
Sunlight	0	54	73	18	50	35

At the item level, approximately 97% of students' responses included the Earth and 90% included the sun as having to do with causing the four seasons. Over 90% of students understand that the cause of the seasons has to do with the relationship between the sun and Earth. Earth's daily rotation about its axis was present in almost 40% of student responses whereas Earth's revolution around the sun was present in 43% of students' responses. Another topic frequently (66%) included in students' mental models is Earth's axis, however only 40% of students mentioned that Earth is tilted. It is possible that students drew Earth's axis out of habit as opposed to contributing Earth's axis to Earth's 23.5° tilt. Approximately 35% of students incorporated the sun's rays into their responses. These results indicate what individual science concepts students primarily associate with the cause of the four seasons. Analysis at the model level sheds light on how students use these individual concepts in relationship to one another to form a mental model of why the United States experiences four seasons.

Model Level

Five mental model categories were identified based on students' responses to the draw-and-explain item: 1. movement of the Earth; 2. position of the sun with respect to Earth; 3. Earth pointing towards and away from the sun; 4. sunlight; and 5. miscellaneous. A description of each mental model is provided in Table 4.

Table 4

<i>Description of Students' Mental Models</i>	
Classification	Description
Movement of the Earth	Earth's rotation about its axis and/or Earth's revolution around the sun is the cause of the four seasons
Position of the sun with respect to Earth	The position of the sun, either close/far or high/low, with respect to Earth is the cause of the four seasons
Earth pointing towards and away from the sun	The northern hemisphere pointing towards and then away from the sun throughout the year is the cause of the four seasons
Sunlight	Various aspects of sunlight is the cause of the four seasons
Miscellaneous	Drawings include non-scientific ideas or ideas that do not fit within one of the four other mental models

To represent students' mental models regarding the cause of the four seasons, a tiered approach was used to convey varying levels of specificity of their scientific understanding. Level 1 represents the broad mental models category, whereas levels 2 and 3 (where applicable) indicate subcategories that were identified based on common ideas found within each mental model. These subcategories provided more detail on students' conceptions, sometimes by illustrating a cause and effect relationship between the various items within each mental model. Level 2 provides more detail than level 1, whereas level 3 provides more detail than level 2. A description of each mental model along with its subcategories is provided below. Table 5 provides a breakdown of the individual elements present within each mental model category. The bold numbers represent the percentage of students within the mental model category, whereas the numbers in italics represent the breakdown of percentages by subcategory (level 2).

Table 5

Percentage (% of responses that included each item within each mental model, by subcategory (Level 2))

Model	Earth	Sun	Axis	Revolution	Rotation	Tilt	Sunlight
Movement	100	81	75	63	56	44	0
<i>Rotation</i>	38	19	31	0	38	13	0
<i>Revolution</i>	44	44	25	44	0	25	0
<i>Rotation & Revolution</i>	19	19	19	19	19	6	0
Position	100	100	38	15	15	23	54
<i>Close/Far</i>	69	69	31	15	15	15	23
<i>High/Low</i>	31	31	8	0	0	8	31
Pointing To/Away	100	91	82	45	45	100	18
<i>Alternating Tilt</i>	55	45	45	0	27	55	9
<i>Revolution</i>	45	45	36	45	18	45	9
Sunlight	100	100	55	73	55	55	73
<i>Rotation</i>	27	27	27	9	27	9	9
<i>Revolution</i>	73	73	45	64	27	45	64

Mental Model 1: Movement of the Earth. Students with this mental model depicted the various movements of Earth as the cause of the four seasons, as shown in Figure 1.

Responses in this category were very vague; thus students do not have a complete understanding as to how Earth's movements contribute to the cause of the seasons.

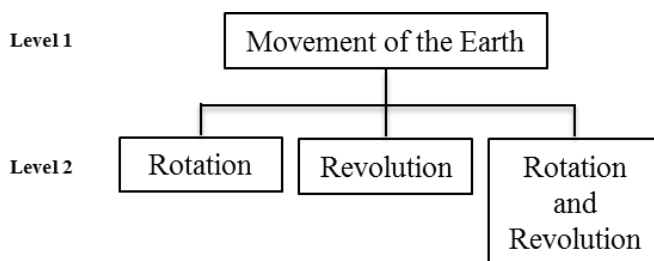


Figure 1. Layers of the mental model category: Movement of the Earth.

One subcategory of the Movement of Earth mental model is rotation. Earth's axis is tilted at a 23.5° angle with Earth making a full rotation about its axis every 24 hours, resulting in parts of Earth experiencing day or night. Approximately 38% of students that

have this mental model consider Earth's rotation to be the cause of the four seasons; however only half of these students mention that Earth's axis is tilted.

The second subcategory of this mental model is revolution, as shown in Figure 2. Earth completes one orbit, or revolution, around the sun in approximately 365 days. Of the responses that fell into this subcategory, approximately 25% drew Earth's axis and included Earth's tilt; however several of these students indicated that Earth's axis changes directions as it orbits the sun. This suggests that students may attribute Earth's revolution *and* changing tilt as the cause of the four seasons, a finding consistent with Hsu (2008), Sharp (1996), and Tsai and Chang (2005).

The final subcategory for this mental model is rotation and revolution. Students in this subcategory attributed the cause of the four seasons to both of Earth's movement. Again, minimal information was provided other than Earth's rotation and revolution being important, which suggests students understanding of how Earth's movement impacts the seasons is fragmented.

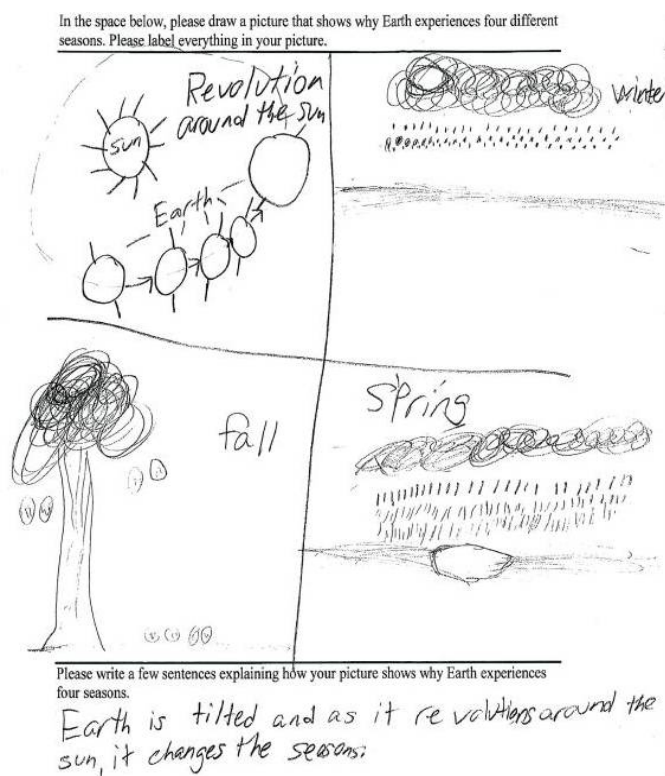


Figure 2. Mental model 1: Movement of the earth.

Mental Model 2: Position of the Sun with respect to the Earth. Responses in this mental model category focused on the position of the sun compared to that of the Earth as the cause of the seasons, as illustrated in Figure 3. More specifically, either the distance between the sun and Earth (close/far) or the movement of the sun in space was said to be the reason for the seasons, as shown in Figure 4.

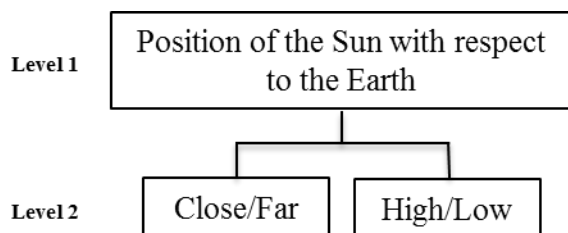


Figure 3. Layers of the mental model category: Position of the sun with respect to the Earth.

Approximately 15% of students indicated the distance between the sun and the Earth as the reason the United States experiences four seasons. Students indicate that the sun “gets closer” and “farther away” throughout the year, with the sun being closer during the summer and farther during the winter (See Figure 3). Although most students within this subcategory do not provide any more explanation than the proximity of the Earth to the sun as causing the seasons, approximately 38% of students do reference the greater amounts of light or heat generated when Earth is closer to the sun. This suggests that students harbor the alternate conception that Earth has an elliptical orbit around the sun, with certain parts of the orbit bringing the Earth within a close proximity to the sun, whereas other parts of the orbit place Earth significantly farther away from the sun. These findings are consistent with those of Baxter (1989), Hsu (2008), Sharp (1996), Trumper (2001), and Tsai and Chang (2005).

According to 7% of the students, the location of the sun in space relative to a stationary Earth caused sunlight to hit the Earth differently throughout the year, resulting in summer, spring, winter, and fall. Of these students, 75% indicate that the sun is higher in the summer and lower in the winter, and 25% indicate the sun moves left to right while the sun stays stationary throughout the year. These students believe that the relationship between the Earth and sun causes the four seasons, however as Earth does not move, the sun’s changing position in space throughout the year causes Earth to experience different seasons. These findings are similar to those of Baxter (1989) who found that students believe the sun moves from one side of the Earth to the other, causing the seasons to change.

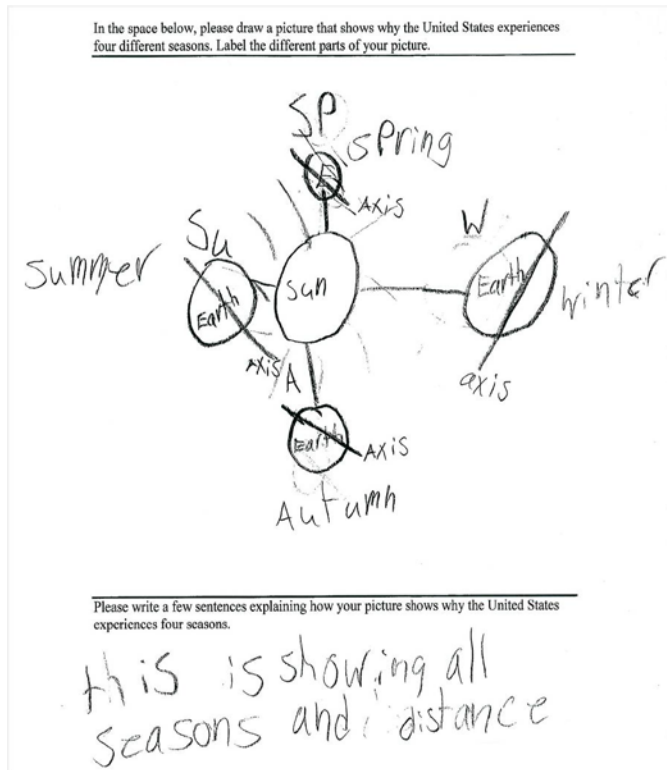


Figure 4. Mental model 2: Position of the sun with respect to the earth.

Mental Model 3: Earth Pointing Towards and Away from the Sun. The students with this mental model attribute the cause of seasons to be specifically due to Earth, or parts of Earth, pointing towards or away from the sun throughout the year, as depicted in Figure 5.

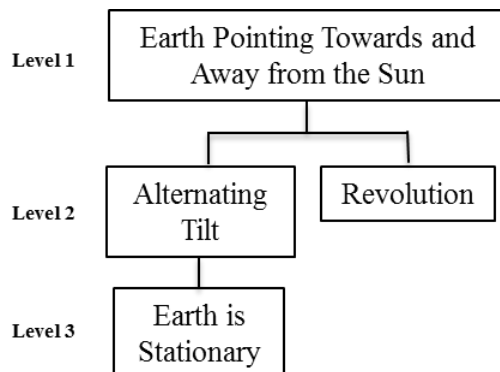


Figure 5. Layers of the mental model category: Earth pointing towards and away from the sun.

Students indicated that Earth experiences summer when Earth is tilted towards the sun and winter when Earth is tilted away from the sun. Over 10% of the students indicated that the Earth remains stationary and the degree at which it is tilted shifts throughout the year, as shown in Figure 6. In other words, the Earth rocks back and forth, much like a rocking chair. The northern hemisphere tilts towards the sun during summer, away from the sun during winter, and both hemispheres are approximately equidistant during fall and spring. To my knowledge, this mental model has not been reported in other studies.

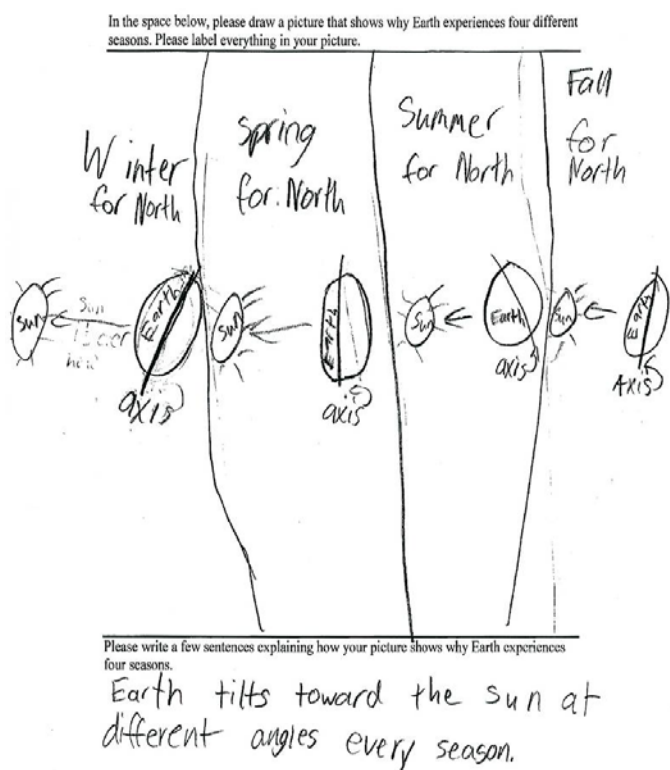


Figure 6. Mental model 3: Earth pointing towards and away from the sun.

Only 8% of the students indicated that the location of the Earth during its orbit causes the northern hemisphere to either point towards or away from the sun throughout the year. Although students in this subcategory mentioned Earth's revolution around the

sun in their responses, only 25% correctly specified that Earth remains at a constant tilt throughout its orbit, which effects which hemisphere is receiving direct light. Oftentimes, students correlated the proximity of the northern hemisphere to the sun to the season; therefore, if the northern hemisphere is tilted towards the sun it is summer, whereas it is winter when the Northern Hemisphere is tilted away from the sun. Baxter (1989) and Tsai and Chang (2005) also found that students contribute the cause of the seasons to Earth's tilt.

Mental Model 4: Sunlight. Approximately 20% of students attributed various aspects of sunlight to causing the four seasons. Many students provide a cause and effect relationship for how sunlight effects which season it is, as depicted in levels two and three. For this mental model, level two causes the effects depicted in level three thus level two and three will be discussed together. Overall, this mental model suggests that students consider the movement of Earth (rotation or revolution) causes the sun to impact Earth in various ways as illustrated in Figure 7. Specifically, revolution and/or rotation affect the area of Earth receiving direct light, the amount of light hitting Earth, or the angle at which the sun's rays are hitting Earth.

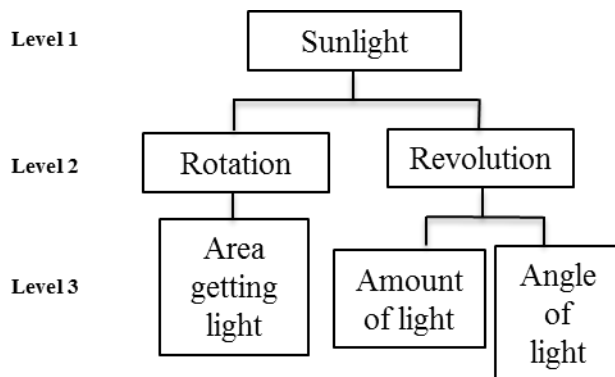
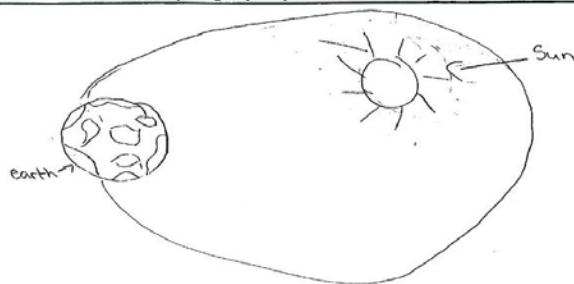


Figure 7. Layers for the mental model category: Sunlight.

Approximately 5% of students suggested that Earth's rotation about its axis effects which area of Earth receives sunlight, as shown in Figure 8. Hsu (2008) also found that students' believe that the side of Earth facing the sun is experiencing summer whereas the side of earth facing away from the sun is experiencing winter. On the other hand, about 14% of students identify the cause of the seasons to be due to Earth's revolution around the sun. Earth's orbit is described as affecting the amount of light the northern hemisphere is receiving or the angle at which the sun's rays hit areas of Earth. These results are similar to those of Bakas and Mikropoulos (2003) who found that students attributed the angle of the sun's rays to why the temperature is hotter in summer than in winter. As a standalone mental model, this category has not been identified as the cause of the four seasons.

In the space below, please draw a picture that shows why Earth experiences four different seasons. Please label everything in your picture.



Please write a few sentences explaining how your picture shows why Earth experiences four seasons.

The Earth spins on its axis. When one side is facing the sun the other side isn't so the side facing the sun is summer and the other side of the Earth is having winter.

Figure 8. Mental model 4: Sunlight.

Mental Model 5: Miscellaneous. Student responses belonging to this category either consisted of scientifically inaccurate information or depicted scientific phenomena that did not fall into one of the mental model categories, as shown in Figure 9. In few instances, students considered the tilt of the Earth to be the sole contributor to the cause of the four seasons; however this idea was not present enough to warrant its own mental model category, nor did this idea fit into one of the pre-existing mental model categories.

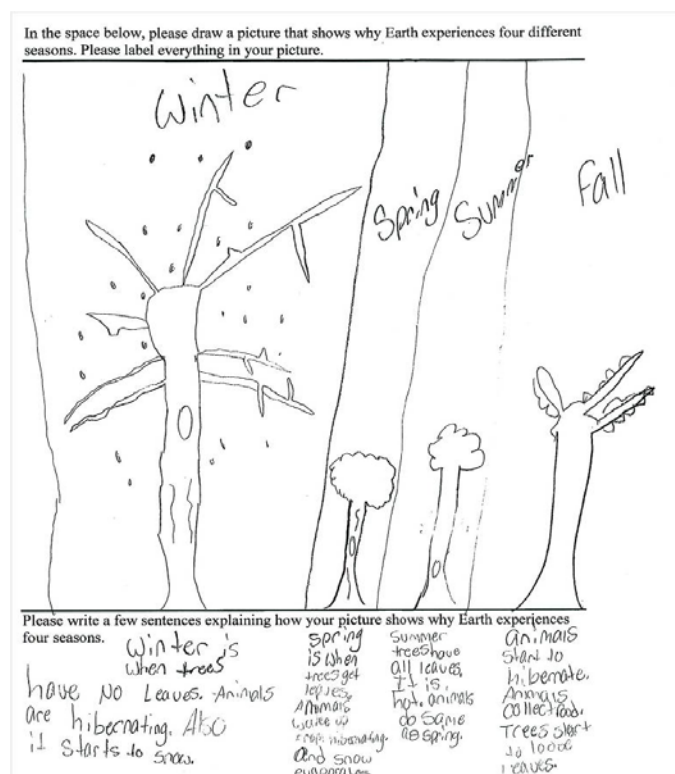


Figure 9. Mental model 5: Miscellaneous.

Mental Models by Student Demographics.

It is important that an assessment item is not biased towards a particular demographic of students; therefore the distribution of students within each mental model category was examined. The breakdown of students within each mental model category by gender and ethnicity is illustrated in Table 6 and Table 7, respectively. The draw-and-

explain item resulted in similar mental model distributions both by gender and by ethnicity, with no particular demographic being placed in the miscellaneous category more often than another demographic.

Table 6

Percentage (%) of Responses within each Mental Model Category by Gender.

Mental Model	Male	Female
Movement of Earth	36	13
Position of the Sun with respect to the Earth	21	25
Sunlight	18	21
Earth Pointing Towards/Away from the Sun	15	25
Miscellaneous	9	17

Table 7

Percentage of Responses within each Mental Model Category by Ethnicity.

Mental Model	White	Hispanic	Other
Movement of Earth	33	21	0
Position of the Sun with respect to the Earth	18	29	33
Sunlight	15	21	33
Earth Pointing Towards/Away from the Sun	23	7	17
Miscellaneous	10	21	17

Conclusion and Implications

This aim of this study was to develop and implement an open response item, specifically a draw-and-explain task, that elicits students' conceptions of the cause of the four seasons and to develop an analytic framework to characterize students' mental models. A draw-and-explain task was created in conjunction with an engineering design task that encouraged students to provide a physical artifact that demonstrated their

understandings of the cause of the four seasons. Multiple rounds of coding and inductive analysis resulted in five mental model classifications: (1) movement of the Earth; (2) position of the sun with respect to Earth; (3) earth pointing towards and away from the sun; (4) sunlight; and (5) miscellaneous. These results, as well as even distribution of students within each mental model category by gender and ethnicity, indicate that this draw-and-explain item is a valid measure of students' conceptions regarding the cause of the four seasons.

The findings of this study suggest that, upon completion of the Seasons and Shadows engineering design task, students harbored a variety of alternate conceptions as to the reason for the seasons. Several of these conceptions included the movement of the Earth, the location of the sun in space with respect to a stationary Earth, and a stationary Earth pointing towards and away from the sun were identified in this study. Two mental models identified in this study have not been reported in other literature on students' conceptions of the cause of the seasons: 1) Earth remains in one position and rocks back and forth resulting in the northern hemisphere tilting towards and away from the sun at various times of the year; and 2) The effects of sunlight impact the cause of the four seasons.

Implications for this study suggest that the use of draw-and-explain task provides an effective means of capturing students' mental models, including the shared and unshared attributes students assign to their ideas. Furthermore, it can be argued that students in this study did indeed harbor various mental models when engaged in an engineering design task related to the four seasons. Results from this study suggest that further research is clearly warranted. Several new questions include the following: In

what ways does engineering design facilitate students' mental models? What are students' mental models as they progress from the beginning to the end of a design task? How do students' mental models compare from students who engage in engineering design versus inquiry? If the expectation is for the integration of engineering practices, attention must be given to how we can best identify, characterize, and understand if and how students can learn science through design and the respective mental models they may hold.

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Appendix A

Shading a Picnic Table

The company that you work for has contracts with cities for construction of facilities for city parks. Recently, several picnic tables were constructed and installed in city parks at several locations around the world (cities at different latitudes). These cities have now asked your company to design structures to provide shade for some of these tables (sometimes it is uncomfortably hot to sit in the Sun at the table). The structure must provide shade during noontime (maximum Sun angle for that location) in both summer and winter (summer and winter solstice). You will have to use what you have learned about seasons, shadows and Sun angles to create an effective and affordable structure.

During this lesson you will:

- Design a structure that will provide the picnic table (lunch area, table and benches) with shade. A scale model drawing of the picnic table is shown below.
- Use the information from your understanding of seasons, shadows and Sun angles (see Table 1) to create an effective model as a prototype of the actual structure that will be constructed.
- Test your model using a flashlight to imitate the Sun's rays.

Design Requirements:

- The structure should shade the entire picnic table and bench area at noontime at your latitude for both summer and winter solstice (see Sun angles for your latitude in Table 1), but should allow some Sun at early and late hours of the day (low Sun angles).
- The structure should be at least 2 meters tall (20 centimeters for your model).
- Must stand up on its own, but can be fixed (permanent location) or moveable depending on season.
- Must be affordable (low cost). The list below shows the materials available and the cost of each item.

Materials (most can be cut to size) and prices

30 cm dowels (or equivalent)	\$1.00 each
Flat Sticks	\$0.50 each
Tape	Free
Card Stock	\$1.00 per sheet
Styrofoam Plates	\$2.00 each
String	\$0.05 per cm
Clay	\$3.00 per strip
Poster Board	\$0.05 per square cm
Foam Board	\$0.10 per square cm
Pipe cleaner	\$0.05 each

Appendix B

In the space below, please draw a picture that shows why the United States experiences four different seasons. Label the different parts of your picture.

Please write a few sentences explaining how your picture shows why the United States experiences four seasons.

CHAPTER TWO: EXAMINING ELEMENTARY SCHOOL STUDENTS' SCIENCE CONCEPTUAL UNDERSTANDINGS THROUGH ENGINEERING DESIGN

Abstract

Recently, science education reform documents have called for the incorporation of scientific principles and practices into the K-12 science curriculum. One this has been achieved is through the use of engineering design tasks as a way for students to apply their scientific knowledge to authentic problems. Recent studies have examined the effect engineering design tasks have on students' understanding of engineering, technology, and science concepts. However, the majority of studies emphasize the accuracy of students' scientific thinking instead of what their conceptions are. This study utilized a draw-and-explain item and semi-structured interviews to elicit students' mental models of sun-Earth relationships after students completed either an engineering design task or traditional learning strategies as part of a science unit. Results indicated students, regardless of the culminating activity, possess similar mental models, although both groups demonstrated learning gains. This indicates that engineering design did not enhance students' scientific understanding, therefore suggestions are made to try and make the use of engineering design more effective in the science classroom.

Introduction

Current instructional practices in the elementary science classroom leave students struggling to understand science concepts and their applications to students' everyday life (National Research Council [NRC], 2008, 2012). Science is typically taught as an overwhelming number of disconnected facts, transmitted from teacher to student in a context-free learning environment via lecture and bookwork (Banilower, Smith, Weiss, & Pasley, 2006; Eisner, 1980). Students are expected to figure out the relationships between individual topics on their own and receive little guidance on how to speak the language of science (Abell & Lederman, 2007; Lemke, 1990; NRC, 2008). Traditionally students "do" science by participating in labs where students follow specific steps and predetermined results are achieved, resulting in poor conceptual understanding of what it means to know and do science (Woodburry & Gess-Newson, 2002). Such teaching strategies prohibit students from immersing themselves in the culture of science, and thus fail to understand how scientific knowledge is constructed and used in the real world (Resnick, 2006). Thus, reform documents have promoted active learning strategies such as scientific practices and engineering design as a means to help students better learn science.

The new framework for science education endorses the integration of engineering practices in the K-12 science classroom (NRC, 2012). Incorporating engineering practices, such as the engineering design process, into the science curriculum can demonstrate the applications of science, provide a context to develop and apply scientific knowledge, and exposes students to the field of engineering (National Academy of Engineering, 2009; NRC, 2012). Students possess a variety of misconceptions about engineering and the work done by engineers (Capobianco, Diefes-Deux, Mena, & Weller,

2011; Fralick, Kearn, Thompson, & Lyons, 2009); therefore, active participation in engineering-based science lessons may paint a more accurate picture of engineering and technology (Alfaro, Barbosa, Ishola, Gorman, Marquez, & Mooney, 2003; Cunningham, LaChapelle, & Lindgren-Streicher, 2005; Ortiz, 2008).

When engaging in the engineering design process, students' progress through an iterative cycle of problem solving, consisting of several distinct phases. The engineering design process begins with the presentation of an ill-structured problem that a client needs solved through the creation of an artifact or process. Students then individually brainstorm possible solutions, which they share with their design team. Within their design team, students discuss the strengths and weakness of each design before deciding on a final design. Students sketch their designs in their engineer's notebook, paying attention to materials, dimensions, and labeling. Next, students construct their design according to their sketch, which then undergoes rigorous testing to determine if it meets the client's criteria. Based on the results of testing, students redesign their artifact or process (Capobianco et al., 2013; Fortus, Krajcik, Hershimer, Marx, & Mamlok-Naaman, 2005; Fortus, Krajcik, Marx, & Mamlok-Naaman, 2004). Although few studies have examined the impact of engineering design tasks on student learning, several advantages of implementing engineering design in the classroom have been reported.

Engineering design has the potential to enhance students' conceptual understanding by placing science learning in an authentic context and providing an opportunity to transform their mental models of science phenomena into physical models that can be tested (Lemons, Carberry, Swan, & Rogers, 2010; Moore, Tank, Glancy, Kersten, & Stohlmann, 2013). In most cases where engineering design was integrated

into the science curriculum, students demonstrated statistically significant learning gains in science and mathematics content, with scores increasing for both low and high achieving students (Fortus et al, 2004; Mooney & Laubach, 2002; Silk, Schunn, & Cary, 2009). The integration of engineering design may also reduce the achievement gap between Caucasian and Asian students and their minority peers (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006; Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Mehalik, Doppelt, & Schunn, 2008). Also, engineering related tasks can result in younger students increasing their science and engineering vocabulary while using scientific words correctly (Roth, 1996). Although these findings suggest that engineering design may foster science learning, more studies are needed to understand how engineering design impacts what students think, as opposed to whether or not they know the correct answer.

The aforementioned studies elucidated potential benefits of integrating engineering into the K-12 science curriculum; however, gaps remain in this body of knowledge. The majority of studies that assessed the impact of engineering design on science learning focused on middle school or high school students (Apedoe, Reynolds, Ellefson, & Schunn 2008; Cantrell et al., 2006; Fortus et al, 2005; Fortus et al, 2004; Mehalik et al, 2008; Sadler, Coyle, & Schwartz, 2000; Silk et al, 2009). State standards and science reform documents now advocate for engineering practices to be integrated in the elementary science curriculum, thus it is necessary to understand how engineering design affects the learning among students at the elementary school level. Also, few research studies compared the effects of engineering design-based tasks on science learning to the effects other teaching strategies have on student learning (Mehalik et al, 2008; Silk et al, 2009). Therefore, this study will contribute to the growing body of

literature on student learning through engineering design in an elementary classroom while also examining the conceptual understanding of students that completed traditional learning activities as opposed to an engineering design task by eliciting students' mental models. Analysis of students' mental models provides valuable insight as to what students understand, and what alternate conceptions they still possess.

Purpose of the Study

Extensive research has been done on students' conceptions of various astronomy topics throughout the last 50 years (Lilliott & Rollnick, 2010). Studies have focused on students' understanding of the shape of the Earth (Blown & Bryce, 2006; Diakidoy, Vosniadou, & Hawks, 1997; Panagiotaki, Nobes, & Potton, 2008; Sharp, 1996; Siegal, Butterworth, & Newcombe, 2004; Tao, Oliver, & Venville, 2013; Vosniadou & Brewer, 1992), spatial relationships and movements of celestial bodies (Bakas & Mikropoulos, 2003; Blown & Bryce, 2006; Jones, Lynch, & Reesink, 1987; Kallery, 2011; Klein, 1982; Plummer, 2009; Trumper, 2001), stars (Dove, 2002), moon phases (Baxter, 1989; Dove, 2002; Sharp, 1996; Trumper, 2001), cause of the seasons (Bakas & Mikropoulos, 2003; Baxter, 1989; Sharp, 1996; Tao et al., 2013; Tsai & Chang, 2005), and the day/night cycle (Bakas & Mikropoulos, 2003; Baxter, 1989; Chiras & Valanides, 2008; Diakidoy et al., 1997; Dove, 2002; Kallery, 2011; Schwarz, Schur, Pensso, & Tayer, 2011; Sharp, 1996; Siegal et al., 2004; Tao et al., 2013; Trumper, 2001; Vosniadou & Brewer, 1994). With respect to the day/night cycle, emphasis has been on the cause of the day/night cycle, with only a few studies examining other components such as the different times and locations where the sun rises, the sun's apparent path across the sky throughout the year, or the length of day (Klein, 1982; Plummer, 2009; Trumper, 2009). The majority of

the studies looking at students' ideas of the day/night cycle utilized semi-structured interviews and questionnaires with multiple choice questions. Although a few studies incorporated drawings into their methodology, few studies utilized drawings as their primary data source. Therefore, a gap remains in the existing knowledge base about more specific ideas within the domain of the day/night cycle, using more open-ended techniques.

The purpose of this study was two-fold: 1) to determine students' science conceptual understanding of sun-earth relationships, specifically the duration of daylight hours and 2) to compare the conceptual understanding of students who completed an engineering design task to those students who completed more traditional science learning activities. Students' conceptual understanding, in the form of mental models, was examined via qualitative methods (e.g. drawings and written explanations) that provided a snapshot of what students consider meaningful and relevant for a specific topic (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001). Students' mental models were not assessed for accuracy, but were characterized to identify essential features of students' ideas. In other words, this study focused on *what* students think about sun-earth relationships, not *if* the students' mental models were scientifically accurate.

Research Questions

This study aimed to elucidate and examine students' mental models about sun-Earth relationships. The research questions guiding this study were:

1. What mental models of sun-earth relationships do elementary school students possess?

2. In what ways do the mental models of elementary school students who completed an engineering design task compare to the mental models of students who completed traditional science learning activities?

Theoretical Framework

Mental Models

Mental models are internal representations, or conceptions, that students construct as they make sense of their everyday interactions with the natural world (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). Johnson-Laird (1983) defined mental models as “structural analogues of the world,” (p. 165). These cognitive structures correspond to, and are consistent with, the phenomena being represented in terms of the individual topics that make up the phenomena and the relationships that exist between those topics; however mental models are not exact replicas of the actual phenomena (Halford, 1993; Norman, 1983). Mental models allow students to understand what causes the phenomena, the factors that influence it, and how to control it (Greca & Moreira, 2001). In other words, the sole purpose of a mental model is to be functional in that students can use it to interpret and explain the phenomenon, enabling the individual to generate inferences and predictions about the phenomena (Franco & Colinviaux, 2000; Greca & Moreira, 2000).

Characteristics of Mental Models

As mental models are derived from personal experiences and the meanings generated from those experiences, a student’s mental models are unique to that individual, and often times incongruent with scientifically accepted models (Driver et al., 1985; Norman, 1983). Mental models are stable (Driver et al., 1985); even after receiving

formal instruction on the scientifically accepted theory, students are cautious about discarding a mental model that has previously helped them understand every-day events (Driver & Oldham, 1986; Duit & Treagust, 1995; Dykstra, Boyle, & Monarch, 1992; McCloskey, 1983). Thus, learning is considered a progression of students' mental models from an inaccurate view to a more scientifically accurate view accepted by the science community (Pope, 1982). Mental models are often incomplete, with gaps existing in students' understandings of a given topic, and students tend to forget portions of their mental models if they are not frequently used, making mental models inconsistent (Norman, 1983). A key feature of mental models is their adaptability. As students encounter novel situations, knowledge, and social interactions, they constantly adapt their mental models (Jones, Ross, Lynam, Perez, & Leitch, 2011).

Eliciting Mental Models

An underlying assumption of research on mental models is that mental models can be accurately depicted through pictures or words (Greca & Moreira, 2000). Several techniques have been used to elicit student conceptions on various science topics. Such techniques include open-ended questions (O-Saki & Samiroden, 1990; Stavy, 1988), drawings (Barraza, 1999; Bowker, 2007; Dove, Everett, & Preece, 1999), and semi-structured interviews (Barton, Koch, Contento, & Hagiwara, 2005; Helldén, 1999; Koulaidis & Christidou, 1999; Mann & Treagust, 2010; Vosniadou & Brewer, 1992). To capture elementary students' mental models, draw-and-explain tasks and open response questions served as the primary data sources. Semi-structured interviews were used to supplement and confirm the researchers' interpretation of students' responses.

Context of the Study

This study is part of a larger project entitled the Science Learning through Engineering Design (SLED) Partnership. SLED aims to enhance elementary school students' science learning by creating an engineering design-based approach to science education. Elementary and intermediate (grades 3-6) school teachers partnered with STEM faculty to develop standards-based engineering design tasks for participating teachers to implement in their classroom. Teachers participated in a two-week long professional development where they completed various engineering design tasks. Teachers were then encouraged to incorporate SLED-created engineering design tasks into their curriculum throughout the academic school year. The teachers participating in this study were recruited from this sample of teachers.

This study examined students' mental models after the completion of one of two instructional methods: engineering design or traditional science learning activities. An overview of the participants of this study, the curriculum unit, and a description of the engineering design task and traditional learning activities completed by the students are described below.

Participants

This study took place at a rural intermediate school located in the central Midwest called Lakeside Intermediate School (pseudonym). The school includes approximately 550 fifth and sixth grade students. Of these students, approximately 23% are Hispanic, 73% are Caucasian, and over 60% of students qualify for free or reduced lunch, as shown in Table 4 (Indiana Department of Education, n.d.). The fifth grade student population of Lakeside Intermediate closely resembles that of the entire school. Compared to the fifth

grade students enrolled in other public schools in the state, there are comparable amount of Caucasian students, but Lakeside Intermediate has a larger Hispanic student population and a smaller Black student population. Similarly, Lakeside intermediate has a slightly higher percentage of students that qualify for free or reduced lunch compared to other fifth graders in Indiana public schools.

Sixty-seven fifth grade students participated in this study. These students were purposefully selected as their teachers, Renee and Lara, participated in SLED during the 2012-2013 academic year and implemented the Seasons and Shadows design task.

Demographic information of the participants is provided in Table 5. Both Renee and Lara had two science classes with 20-25 students per class. The teachers selected one of their classes to complete the Seasons and Shadows design task as a culminating activity to the Universe unit (treatment group, n=37) and their other class to complete more traditional learning activities (control group, n=30) throughout the entire unit. Students from both groups completed the same activities leading up to the culminating activity of the sun-Earth section of the unit, thus the only difference between the two groups is the series of culminating activities which are described below.

Table 8

Student Demographic Information of Lakeside Intermediate School

Level	Gender		Race/Ethnicity		
	Male	Female	Caucasian	Black	Hispanic
2013-2014					
Lakeside	51.3	48.7	72.9	1.7	22.7
Lakeside Grade 5	47.4	52.6	73.2	1.5	22.3
Indiana Public Schools Grade 5	N/A	N/A	71.5	12.3	9.6

Table 9

Profile of Student Participants

Group	Gender		Ethnicity		
	Male	Female	Caucasian	Hispanic	Other
Treatment	42%	58%	69%	19%	11%
Control	45%	55%	70%	24%	6%

Curriculum unit

Teachers from the treatment and control groups began their school year with science unit referred to as the Universe unit. This unit addressed the following science concepts: earth and sun relationship, the earth and moon relationship, the solar system, and the stars (Hacket, Moyer, Vasuez, Teferi, Zike, LeRoy, Terman, & Wheeler, 2011). This study focuses on students' understanding of various sun-Earth relationships including Earth's tilt, Earth's rotation about its axis, Earth's revolution around the sun, and the sun's apparent path across the sky.

Students from both the treatment and control groups participated in class discussions around the following questions: Why do we have more daylight in the summer than in the winter? Why is it warmer in the summer and colder in the winter? How much daylight do we have in the summer vs. the winter? How do the sunrise/sunset times change throughout the year? Students prepared a Rotation/Revolution flip chart in their science notebooks to reinforce their understandings of these respective concepts. Students also discussed the features associated with summer and winter in the Northern Hemisphere; how the sun's position changes in the sky during the course of a year; and the cause of the four seasons. Following these class discussions, student participants were split into two groups, treatment and control, and engaged in the activities outlined below.

The treatment group participated in an engineering design task whereas the control group completed a series of traditional science learning activities. Both activities required students to understand and apply their knowledge of the reason the amount of daylight is longer during the summer than the winter.

Seasons and Shadows Design Task

Students in the treatment group were introduced to an engineering design task using a design brief. The brief represents a narrative that provides the context of the design task. The design brief includes a description of the client, end user, the problem that needs to be solved, as well as the constraints students have to work within when solving the problem (Capobianco et al., 2013). For the Seasons and Shadows design task, students were asked to design a structure that would shade a picnic table at lunchtime throughout the entire year (See Appendix A). To solve this problem, students then worked in small teams and applied their understanding of the cause of the seasons, shadows, and sun angles to create a shading structure. Design constraints included the following: (a) the picnic table and benches are fully shaded at noontime; (b) the structure is at least two meters tall; (c) minimum cost; and (d) the structure must be free-standing. To complete the task, students needed to understand the sun's apparent path across the sky during the day, the earth's tilt, earth's revolution around the sun, the cause of the seasons, and how the sun's trajectory across the sky is influenced by the different seasons.

Science Learning Activities

Students in the control group read and discussed the book entitled, *The Reasons for the Seasons* by Gail Gibbons with emphasis on the four seasons and why we have them. Students then watched a Bill Nye video which provided students with basic

information about the sun as well as BrainPop video about solstices, equinoxes, the sun's changing path throughout the year, and how the Earth's tilt creates longer and shorter days. Finally, students completed a graphic about Earth's rotation about its axis and its revolution around the sun.

Mixed Methods Research Design

A quasi-experimental mixed methods research design was chosen for this study (Creswell, 2014). A pre- and post-knowledge test was administered before and after the unit to determine students' knowledge of the sun-Earth relationships prior to instruction (pre-test) and following the completion of the engineering design task and traditional science learning strategies (post-test). However, the primary focus of this study was to elicit and characterize students' mental models, thus the majority of this research study focused in the elicitation of students' mental models which involved two distinct, sequential phases.

The first phase entailed identifying and characterizing students' mental models for the reason the United States experiences more daylight hours during the summer than the winter. The qualitative aspect of this research design is based on the idea that the words and images students use reflect what they consider most meaningful and significant about a particular concept (Kress et al., 2001); therefore drawings coupled with semi-structured interviews provided the researcher the opportunity to inspect the characteristics of each student's mental models in order to synthesize an understanding of students' reasoning behind their conceptions. In other words, *what* do students think and *why* do they think that way? Qualitative data in the form of pictures and words, spoken and written, were used to analyze students' mental models.

The second phase involved determining the number of students from the treatment group and comparison group that possess each mental model identified during phase one. A comparison of the frequency distribution of mental models for each group demonstrated the type of understanding each instructional method fostered. Statistical analysis determined if a relationship exists between instructional method and learning outcomes.

Data Collection

Knowledge tests

Prior to the start of the unit students completed a 12 item multiple-choice pre-test that assessed their understanding of rotation, revolution, the cause of the seasons, and the sun's path across the sky. Pre-test scores were used to ensure that students from Lara's control group class and Renee's control group class were similar and could therefore be merged into one control group. Similarly, pre-test scores were completed for both Lara and Renee's treatment groups to determine if they could be merged into one large treatment group. Once the classes were merged, overall pre-test scores from both groups were compared to determine if both groups entered this study with a similar knowledge base. Students completed the same 12 item knowledge test at the very end of the unit to assess for learning gains. All participants completed both the pre-test and the post-test.

Draw-and-explain item

The instrument used in this study was a draw-and-explain item created to assess students' knowledge of why the amount of daylight hours is longer during the summer than in the winter (see Appendix A). This item was created using the same process described in previous work (Dankenbring & Capobianco, under review). The relevant

science standards were identified and deconstructed into the smaller concepts that students need to know. Next, relevant literature was reviewed to find out what types of assessment items have been used to elicit students' mental models. Once a format (draw-and-explain) was selected, example assessment questions were reviewed to determine age appropriate diction and syntax. Sample items were then drafted and piloted to ensure students were able to understand and properly respond to the assessment item.

Drawings provide a visual image of students' mental models, including the individual topics and relationships between them, information that may be hidden from other techniques. A written description of the drawing provides students the opportunity to explain and elaborate on their picture while also assisting the researcher in correctly interpreting it (Glynn & Duit, 1995; White & Gunstone, 1992). Although not every detail of a students' model can be depicted on paper, the essence of their understanding can be. Drawings portray the meaning behind a student's thinking, but they are not exact replicas of the mental model (Alerby, 2000). Drawings serve as another medium for communicating ideas, allowing students that struggle to express themselves using words or written text to demonstrate their understanding (Rennie & Jarvis, 1995). The use of pictures enables students to put their ideas about abstract concepts on paper and for students with language deficits, enabling educators to gather information that may be inaccessible through other techniques (Rennie & Jarvis, 1995; White & Gunstone, 1992).

Drawings, like all research methods, have their limitations. The contents of the picture may be restricted by the student's ability to put their thoughts onto paper (Arnold, Sarge, & Worrall, 1995). Drawings can be challenging to interpret and difficult to analyze, and therefore should be used as one method of data collection (White &

Gunstone, 1992). Many science concepts are very complex and students are unlikely to portray their mental model in its entirety in the picture or its accompanying text; therefore students likely know more than they reveal (Strommen, 1995). For instance, students may not provide definitions or relationships between individual topics, both of which are important components of a mental model, thus reinforcing the notion that drawings should be supplemented with interviews or other idea eliciting tasks to gain a thorough understanding of students' mental models. Rennie and Jarvis (1995) found that some students drew very simple pictures that lacked the breadth and depth of their knowledge or ideas.

After completing all classroom activities pertaining to the sun-Earth concepts, Lara and Renee administered the draw-and explain item in their classroom (n=67). Lara and Renee read the prompt aloud and students were given as much time as necessary to complete the item. Students were asked to draw a picture that depicts their understanding of what effects the amount of daylight the United States experiences during summer and winter and to provide a written explanation of their drawing.

Within a week of completing the draw-and-explain items, individual semi-structured interviews were conducted with all participants present that day (n=64). These interviews included questions about different components of each student's picture and written response. This ensured that the researchers correctly interpreted each student's response, but also provided the student an opportunity to elaborate on his/her thinking or to change his/her response if he/she did not agree with his/her original response. If the student did not mention how their drawing and/or explanation accounted for more hours of daylight during the summer than winter, he/she was specifically asked how their ideas

account for that phenomenon. For example, if a student indicated that the path of the sun is higher in the sky during the summer and provided no further explanation as to what effect this has on the amount of daylight, the interviewer asked “How does the sun being higher in the sky effect the amount of daylight we receive?”

Data Analysis

Knowledge Tests

Descriptive statistics were performed on the students’ pre and post knowledge test scores. Pre and post-test scores were analyzed using a two-sided t-test to determine if students entered the study with a similar understanding of the science concepts and to determine if post-test scores were significantly higher for students in a particular group and to assess learning gains.

Phase One

Responses to the draw-and-explain task were analyzed at both the item and model level. Individual components of the students’ drawings and written responses were recorded and the frequency determined. An analytic framework was established for characterizing students’ responses at the model level during an unpublished pilot study in which inductive analysis was used to develop an in depth coding system and categorical model system. Multiple rounds of coding extracted students specific scientific ideas related to sun-Earth relationships. Formation of mental model categories involved deconstructing and cataloging the “big idea” of each student’s response and collapsing the big ideas into 5 reoccurring ideas. Finally, individual student responses were independently placed within a particular mental model category, and inter-rater reliability (>90%) was determined. Since each mental model category represents an overarching

scientific idea, subcategories were created to provide a more elaborate explanation of students' conceptions.

Phase Two

The second phase of this study entailed determining if the mental models of students who completed an engineering design task differed from students who completed traditional science learning activities. As both variables are categorical (mental model category and group type), and the 2X2 contingency table yielded small numbers, a two-sided Fishers test was used to determine if there was a significant difference between the number of students from each group that held a certain mental model.

Results

Knowledge Tests

Lara and Renee each had one control class and one treatment class, thus pre-test scores were compared for both control classes to determine if each class had similar understandings; the same was done for both treatment classes, as illustrated in Table 6. A two-sided t-test showed that Lara and Renee's control classes had similar conceptual understanding prior to the start of the unit ($p > 0.05$), as did both treatment group classes ($p > 0.05$), therefore each teacher's respective group was compiled into one control group and one treatment group for the remainder of data analysis. There was a statistically significant difference between the pre-test scores for the merged control group and treatment group ($p < 0.05$). The treatment group had a lower pre-test score than the control group; therefore these students initially had a weaker understanding of the concepts addressed in this unit.

Table 10

Pre-test Scores by Teacher

	n	Mean	Standard Deviation	t	df	p
Lara's Control	12	6.67	1.56	-1.03	27.1	0.31
Renee's Control	18	7.33	1.97			
Lara's Treatment	18	5.89	1.75	-0.37	31.7	0.71
Renee's Treatment	19	6.16	2.59			
Merged Control	30	7.1	1.8	2.12	64.96	0.038
Merged Treatment	37	6.02	2.19			

To determine if students gained knowledge about sun-Earth relationships after the completion of the unit, two-sided t-tests were used to examine students' post-test scores as well as learning gains. There was no statistically significant difference between the post-test scores of the control group and the treatment group, as shown in Table 7.

Table 11

Post-test Scores by Group

	n	Mean	Standard deviation	t	df	p
Control	30	8.37	2.06	0.990	65	0.33
Treatment	37	7.81	2.54			

A comparison of students' pre-test scores to their post-test scores was done to determine if students' gained conceptual understanding of the science concepts throughout the unit, as shown in Table 8. A two-sided t-test indicated that the control group demonstrated statistically significant learning gains ($p < 0.05$) throughout the course of the unit. Similarly, the treatment groups also had statistically significant learning gains at the end of the unit. There was no significant difference between the learning gains observed in the control group and those of the treatment group ($p > 0.05$).

Table 12

Learning Gains by Group

	n	Mean	Standard deviation	t	df	p
Control	30	1.3	2.32	3.067	29	.005
Treatment	37	1.78	2.15	5.05	36	0.00
Control vs treatment	N/A	N/A	N/A	-0.37	31.70	0.71

Phase One

Student drawings and written responses were analyzed on two different levels: item and model. Analysis at the item level entailed cataloging recurring items present in students' responses along with the frequency of each item as shown in Table 9. Analysis at the model level involved the presentation of unique ideas, individual elements and the relationships that exist between them that comprised common models across the sample of student participants.

Item Level. Identifying the individual components of students' mental model provides clues as to what individual ideas students find relevant and important with respect to the phenomenon being represented. These ideas are presented in Table 9. Every student's response included the sun and the Earth which suggests that students understand that there is a relationship between these two celestial bodies that affects the amount of daylight hours North America experiences during the different seasons.

Earth is tilted at a 23 degree angle on an imaginary axis, which impacts two important astronomy phenomenon: the day/night cycle and the cause of the four seasons. Approximately 88% of students' illustrated Earth's axis in their drawings; however, only 70% discussed the Earth being tilted on this imaginary axis in their written explanations. Thus it is possible that students drew Earth's axis because that is how Earth was

presented in class or their textbooks; therefore Earth's axis may not be a critical component of all students' mental models even if it was included in their drawing. The nature of the Earth's tilt was revealed to be a source of confusion for some students as approximately 15% of the students believe the Earth's tilt alternates directions throughout the year, either as Earth revolves around the sun or as a stationary Earth rocks back and forth on its axis.

Table 13

Item Level Analysis of Student Responses to the Draw-and-Explain Item

Item	Percentage of Students
Sun	100
Earth	100
Axis	88
Revolution	69
Sun's Rays	27
<i>Direct</i>	15
<i>Indirect</i>	10
Tilted Earth	27
<i>Consistent</i>	59
<i>Alternating</i>	13
Rotation	12

Earth has two forms of movement which correspond to the primary relationships that exist between the Earth and the sun: Earth's daily rotation around its tilted axis, which accounts for the day/night cycle, and Earth's annual revolution around the sun, which contributes to the cause of the four seasons. Earth's revolution around the sun was present in approximately 70% of students' responses. This idea was typically represented in students' drawings by showing Earth in four different positions around the sun, usually labeled by season, or by showing Earth on both the left and right side of the sun. The

Earth's daily rotation about its axis was only present in approximately 10% of students' responses. This topic was rarely depicted in students' drawings; rather students included this idea in their written responses.

Another idea present in students' responses to the draw-and-explain item was the sun's rays. Approximately 30% of students consider sunlight to be an important feature of the duration of daylight hours, and this idea was illustrated by drawing lines radiating outwards from the sun and hitting Earth in various spots. Two types of sun rays exist, direct rays which result in more intense sunlight, and indirect rays which result in less intense sunlight. The types of rays hitting the United States depend on where Earth is in its rotation around the sun. Approximately 15% of students specifically discussed the effects of direct rays whereas only 10% of students discussed the impact of indirect rays. When specific types of rays were mentioned, it was through students' written responses or by labelling their drawing to specify which lines represented direct rays versus indirect rays.

Although most of these individual topics were discussed by a large percentage of the participants, the specific relationships between these topics cannot be depicted by a catalog of items. Therefore, analysis at the model level is necessary to shed light on how students form relationships between these individual elements to create a mental model. A description of each mental model along with the individual ideas pertaining to each model is explained in detail in the following section.

Model Level. Results of model level analysis depict the individual ideas students consider relevant and the relationships that exist between those ideas. Five mental models were identified and characterized in this study. These models, presented from most to

least frequent, are: 1. tilt of the Earth; 2. sunlight; 3. distance; 4. path of the sun; and 5. miscellaneous. The predominant ideas featured within each mental model category are provided in Table 10 and elaborated on in the description of each mental model found below.

Table 14

<i>Percentage (%) of Individual Ideas by Mental Model Category</i>					
Item	Mental Model				
	Tilt	Distance	Sunlight	Path	Miscellaneous
Sun	100	100	100	100	100
Earth	100	100	100	100	100
Axis	94	63	100	57	100
Revolution	78	50	64	43	80
Sun's Rays	19	0	82	14	20
<i>Direct</i>	11	0	45	0	20
<i>Indirect</i>	6	0	36	0	20
Tilted Earth	42	0	18	0	20
<i>Consistent</i>	64	25	64	43	80
<i>Alternating</i>	19	13	0	14	0
Rotation	11	13	9	29	0

Mental model 1: Tilt of the earth. The majority of students in this study (approximately 74%) attributed the tilt of the Earth to how much daylight the Northern Hemisphere receives during the summer and winter months. Within this category, two main ideas were present. The predominant mental model, illustrated in Figure 10, was that Earth's consistent tilt results in the Northern Hemisphere being tilted towards or away from the sun at certain places along its orbit which affects the amount of daylight we receive. As seen in Table 10, approximately 80% of students with this mental model drew Earth revolving around the sun, and 65% of students indicated that Earth's tilt

remains at the same angle throughout its revolution. As one student explained, in “summer we are facing towards [the sun] so that’s how we get more daylight and we get less daylight in the winter because we’re facing away from the sun.” The phrases “tilted,” “pointed,” and “facing” were used interchangeably to describe the position of the Northern Hemisphere with respect to the sun. Students indicated that when the Northern Hemisphere is tilted toward the sun, it is summer and therefore there is “more sun.” In other words, the close proximity of the Northern Hemisphere to the sun results in more direct sunlight and longer exposure to the sun.

On the other hand, 20% of student responses within this mental model suggested that the Earth remains stationary and rocks back and forth, resulting in the Earth’s tilt changing direction throughout the year. Typically, students with this idea drew two pictures; one picture showed the sun and Earth with the Northern hemisphere tilted towards the sun whereas the other picture had the sun and Earth in the same position but the axis was drawn such that the Northern Hemisphere was tilted away from the sun. Students again emphasized the position of the Northern Hemisphere to the sun, and that facing towards the sun results in more light which gives us longer amounts of daylight.

In North America, the amount of daylight is longer during the summer and shorter during the winter. Please draw a picture that explains why this happens. Label everything in your drawing.



Please write a few sentences explaining how your picture shows why the amount of daylight is longer during the summer and shorter during the winter.

In the summer daylight is longer because the Northern part of earth is facing the sun.

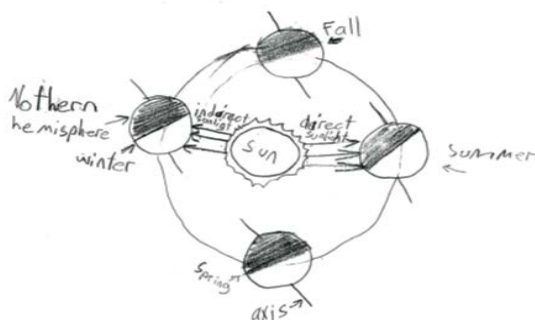
The winter days are shorter because the Northern part of earth is facing away from the sun.

Figure 10. Mental model 1: Tilt of the earth.

Mental model 2: Sunlight. Student responses in this category suggested different aspects of sunlight affect the amount of daylight hours during the summer and winter seasons (see Figure 11). Specifically, approximately 16% of students consider the type of rays (direct or indirect), the amount of sunlight, or the area of earth the sun's rays are hitting as the primary cause of this phenomenon. Of the students with this mental model, over 60% included the impact of Earth's consistent tilt, 64% illustrated Earth's revolution around the sun and 82% of students indicated that the sun's rays were important for determining the amount of daylight the Northern Hemisphere experiences. Direct and indirect rays were specifically mentioned by 45% and 36% of students, respectively. This characterization was also confirmed in student interviews. For example, one student stated, "In the summer, the sun is giving direct sunlight to the Northern Hemisphere so

we get longer days but in the winter we get indirect sunlight so we get shorter days...because it is dimmer during the day so we don't get that much sunlight and it will get darker faster." This illustrates the idea that we get different types of sunlight throughout the year which impacts how much daylight the Northern Hemisphere receives. Rather than the type of light changing from summer to winter, students focused on the amount of light suggesting that we experience "more" or "less" amounts of direct light.

In North America, the amount of daylight is longer during the summer and shorter during the winter. Please draw a picture that explains why this happens. Label everything in your drawing.



Please write a few sentences explaining how your picture shows why the amount of daylight is longer during the summer and shorter during the winter.

It shows because when the sun has direct sunlight we have the most sunlight so it makes the days longer that summer. The days are shorter when we have indirect sunlight that's when we have less sunlight so it makes the days shorter that's winter.

Figure 11. Mental model 2: Sunlight.

Mental model 3: Distance. Approximately 12% of students suggested that the distance between the sun and Earth affects the amount of daylight hours during the different seasons (see Figure 12)., One student stated that "in the summer the days are longer because Earth is closer to the sun and in winter it's not as close to the sun." Of the students within this mental model category, 50% mentioned Earth's revolution around the

sun which suggests that these students harbor the alternate conception that the Earth has an elliptical orbit around the sun, and consequently Earth's proximity to the sun changes during the year. On the other hand, 43% of students indicated that the Earth remains on one side of the sun but moves towards and away from it throughout the year.

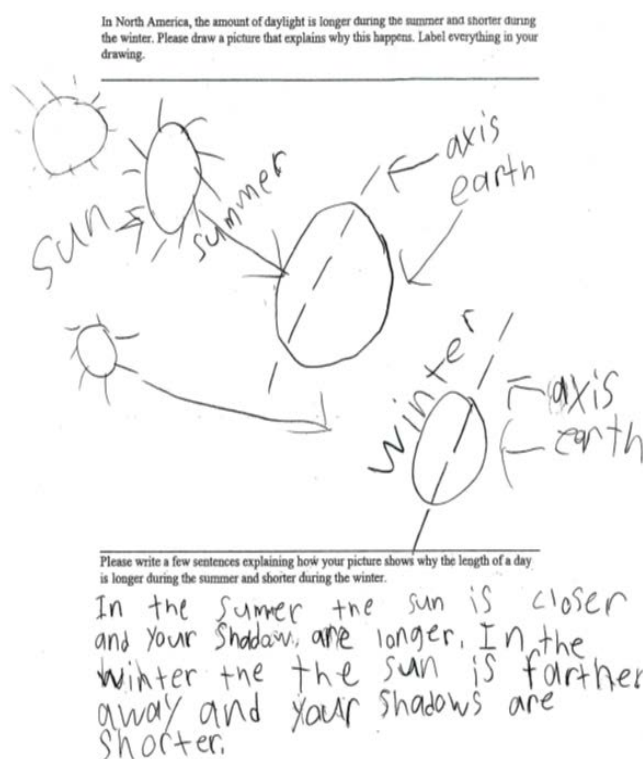


Figure 12. Mental model 3: Distance.

Mental model 4: Path of the sun. Students with this mental model attributed the length of daylight hours to the sun's apparent path across the sky throughout the day. According to 10% of the students' responses, the sun's path across sky is higher in the summer and lower in the winter. According to students, the sun's path impacts the amount of daylight because in the summer "it takes a longer path across the sky so it takes longer to go up and down and across the sky," whereas the shorter path in winter does not take as long to complete. As shown in Figure 13, students in this category often

drew a picture of what the sun's path looks like during the summer and winter or stated the amount of time it takes for the sun to complete its path. Students did not indicate what elements contribute to this phenomenon, nor did they elaborate on why the sun has a different path during the summer and winter in their drawings or written explanations.

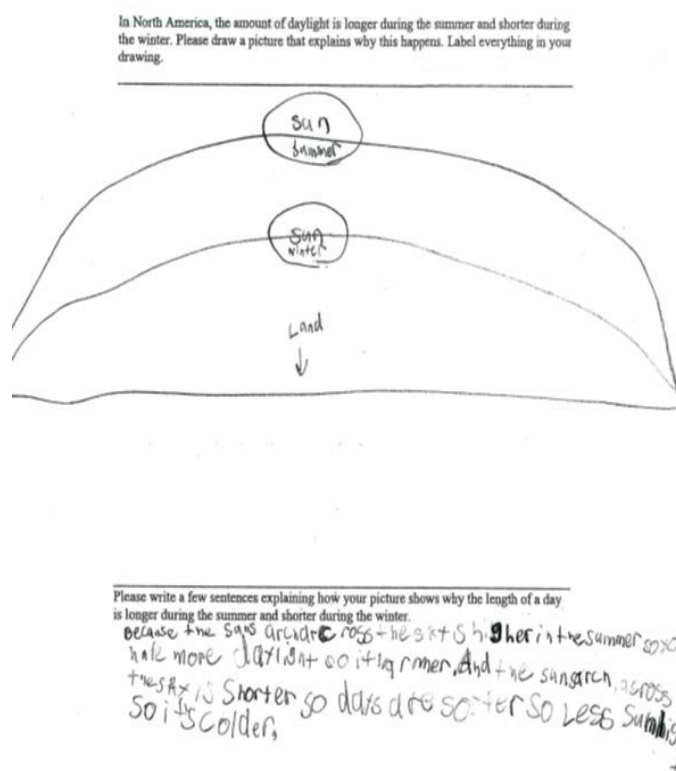


Figure 13. Mental model 4: Path of the Sun.

Mental model 5: Miscellaneous. Student responses placed in this category provided responses that did not address the question, were too difficult to interpret, or portrayed ideas that did not fall into one of the mental model categories (see Figure 14).

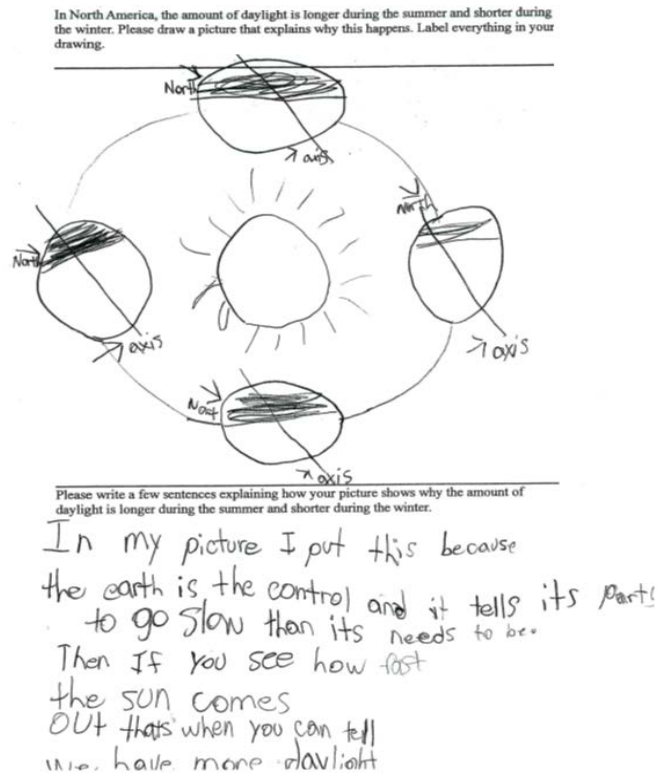


Figure 14. Mental model 5: Miscellaneous.

Phase Two

A two-sided Fisher's exact test was done to determine the distribution of students' mental models based on method (draw-and-explain and semi-structured interviews) and there was no significant difference ($p > 0.05$), which indicates that both methods yielded similar mental model classifications. Thus the mental models identified are both valid and stable.

Our second research question aims to elucidate if the distribution of student responses within a mental model category would differ if students completed an engineering design task as a culminating activity. The percentage of students within each mental model category was similar when compared by group and by teacher, as shown in Table 12 and Table 13 respectively. A two-sided Fisher's exact test determined there was

no statistically significant difference between the distribution of students within each mental model category based on group ($p>0.05$). Also, there was no significant difference in the distribution of students that fell into a particular mental model category ($p>0.05$) suggesting that no mental model category was more prevalent than the others.

Table 15

Mental Model Frequencies by Group

Mental Model	Control	Treatment	Total
Tilt	16 (53%)	20 (56%)	36 (54%)
Sunlight	7 (23%)	4 (11%)	11 (16%)
Distance	3 (10%)	5 (14%)	8 (12%)
Path	3 (10%)	4 (11%)	7 (10%)
Miscellaneous	2 (7%)	3 (8%)	5 (7%)

Table 16

Mental Model Frequencies by Teacher

Mental Model	Adams	Newton	Total
Tilt	16 (52%)	20 (56%)	36 (54%)
Sunlight	6 (19%)	5 (14%)	11 (16%)
Distance	3 (10%)	5 (14%)	8 (12%)
Path	1 (10%)	6 (17%)	7 (10%)
Miscellaneous	4 (13%)	1 (3%)	5 (7%)

Discussion

Although there was no significant difference between the control group and treatment group in terms of learning gains, it appears that students demonstrated relatively positive growth in understanding the science concepts covered in this unit. However, the mental models identified in this study indicate that students still harbor a variety of alternate conceptions, and possibly conflicting ideas regarding various sun-Earth relationships. The different methodologies used to elicit students' conceptual understanding may explain these results.

Yarroch (1991) showed that multiple choice tests often overestimated students' knowledge because students could select the right answer for the wrong reason. This finding was supported by Tamir (1990) who found that only half of the participants who answered a multiple choice question correctly, could provide a complete and correct justification as to why that answer was right. Students are able to use key-words or logic, as opposed to their mental models, to correctly answer multiple choice questions, or they can select an answer at random (Ruane, 2005; Tamir, 1989). Thus, multiple choice knowledge tests may be misleading when representing what students know.

On the other hand, open-ended items enable the researcher to get inside the minds of the students by having them express their thoughts on paper. To correctly answer an open-ended question, students rely on their conceptual understanding of the science concept, thus students' responses more accurately reflect what the student actually thinks (Ruane, 2005; Tamir, 1989). Every student's mental model is a unique depiction of their conceptual understanding; therefore, the use of open-ended questions allows students to provide a range of responses to depict their understanding (Johnson & Christenson, 2012). This was the case for the present study, as five distinct mental models were identified and characterized regarding students' conceptions of the duration of daylight hours throughout the year.

Although the purpose of this study was not to assess the accuracy of students' mental models, it is possible to make inferences about the nature of them using Vosniadou and Brewer's (1992) classification framework of students' mental models. The first classification of mental models is *initial* models, which are constrained by various presuppositions students form from their every day, personal experiences. As

students acquire more scientifically accepted ideas about a phenomenon, they try to “reconcile their presuppositions with the information they receive from the adult culture” and form *synthetic* mental models (Vosniadou & Brewer, 1992, p. 579). With respect to their mental models, students attempt to integrate new information into their preexisting cognitive structures in such a way that they can hold on to, or revise, many of their presuppositions. The final category of mental models is the *scientific* mental model which requires students to reinterpret their original assumptions of how the world works.

Unlike the majority of studies examining students’ understanding of astronomy concepts, no initial mental models were identified in this study. Rather, the results of this study demonstrate a range of synthetic mental models students have for the cause of different amounts of daylight in the summer and winter. Furthermore, some students’ mental models aligned closely with the scientific model accepted by the scientific community. For instance, the mental model category “distance” is synthetic due to the attempted incorporation of the students’ knowledge regarding the cause of the seasons; however, these students still hold onto many assumptions that characterize initial mental models. One assumption may stem from students’ personal experiences with a light source; the closer you are to the light source, the greater the amount of light and heat you receive. At the other end of the continuum, students that attribute the amount of daylight to Earth’s consistent tilt as it revolves around the sun, along with the type of rays hitting the Northern Hemisphere at certain points along its orbit, have a more scientific mental model. It is important to note that throughout the learning process, students’ mental models of a phenomenon progress along this continuum, therefore, a wide range of ideas is to be expected (Glynn & Duit, 1995).

The range of mental models elicited in this study came from students' attempts to integrate new scientific information regarding various science concepts into their existing knowledge structure throughout the unit, which reflects the process of generating synthetic models. The majority of participants in this study referenced the cause of the four seasons in their drawings, written explanations, and/or interviews even though the draw-and-explain item specifically asked why the amount of daylight is different during summer and winter. This implies that students were attempting to integrate their understanding of the seasons with what they know about the day/night cycle in order to address the prompt.

The mental models categories identified in this paper are not new; these models have been identified in the literature on the cause of the seasons, day/night cycle, and other astronomical phenomenon. For example, Bakas and Mikropoulos (2003) investigated students' ideas about why the temperature is hotter in the summer than in the winter, and students provided explanations that align with the sunlight, distance, and path of the sun models discussed in this study. Vosniadou and Brewer (1992) argue that mental models are constructed spontaneously when confronted with a new context. In their attempts to explain why the duration of daylight hours differs throughout the year, students likely accessed other knowledge domains and integrated what they perceived to be relevant information into their existing mental model. Although the mental models identified in this study match those found in studies on other astronomical phenomenon, this is the first study that thoroughly examines students' mental models of the duration of daylight hours throughout the year.

Conclusions

Although many studies have examined students' conceptions of the cause of the day/night cycle, very few have looked at why the amount of daylight changes throughout the year (Chiras & Valanides, 2001). Therefore, the primary purpose of this study was to elucidate and characterize students' mental models of sun-Earth relationships following the completion of either an engineering design task or traditional learning activities. To do so, a draw-and-explain item was created and implemented in four classrooms; two classrooms completed an engineering design task as a culminating activity, whereas the other two completed more traditional learning activities. Students' drawings and accompanying explanations were categorized into one of five mental models: 1. tilt of the Earth; 2. sunlight; 3. distance; 4. path of the sun; and 5. miscellaneous. Semi-structured interviews verified the validity and stability of these mental models.

Mental models consist of individual elements, or ideas, and the relationships that connect these ideas to one another. Of the identified mental model categories, four of them emphasized multiple elements found within the scientifically accepted conceptual model of this phenomenon including Earth's tilt, revolution around the sun, sun's apparent path in the sky changing throughout the year, and types of sunlight. What differentiates these mental models from each other, and from the conceptual model, are how these individual elements are connected to one another. Oftentimes students' drawings and written explanations reflected limited relationships and/or cause and effect reasoning between isolated ideas. These findings indicated that students held, at best, a fragmented understanding of what causes the amount of daylight to change from summer to winter.

Students in both the control group and treatment group achieved significant learning gains throughout this unit, as indicated by their pretest and posttest scores. Although the difference was not statistically significant, students in the treatment group demonstrated higher learning gains than students in the control group. This could be explained by the fact that students in the treatment group began the unit with less content knowledge than the control group, but ended the unit with similar levels of understanding. The treatment group also held similar mental models as the control group, which suggests that engineering design may not enhance the quantity or quality of relationships that exist within students' mental models when used as a culminating activity. However, there was a statistically significant difference in learning gains ($p < 0.05$) when comparing the respective teacher's students, which suggests that learning may be impacted by how the design task is taught.

We speculate that the instructional choices the teachers made, such as emphasizing certain phases of the engineering design process, connecting science concepts to each phase of the design process, or conversations they had with students throughout the design task, may have contributed to students' conceptual understandings. For example, Hynes (2012) assessed seven middle school teachers' understanding and use of each step of the design process within a science unit and found that some teachers scored low on developing and selecting possible solutions to the problem. This phase provides students an opportunity to use their mental models to create and test physical models (Lemons et al., 2010). By externalizing and manipulating their mental models through iterative participation in the design process, students can confront their alternate conceptions and modify existing cognitive structures. Similarly, the way the design task

was used within the unit may explain why students from the treatment group held similar conceptions as students in the control group.

Learning can be viewed as the continuous revision of one's mental model through the processes of enrichment or revision (Vosniadou, 1994). The incorporation of new information into a mental model is known as enrichment whereas revision consists of a structural change in one's mental model as a result of changes in assumptions or beliefs. As the engineering design task was used as a culminating activity in this study, it is likely that students had already constructed their mental models prior to this final activity and failed to correct or revise their alternate conceptions during the design task. As opposed to implementing engineering design tasks as a single culminating activity, many studies that examined the impact of engineering design on student learning used a design-based unit where engineering design constantly introduced and reinforced science concepts (Cantrell et al., 2006; Fortus et al., 2004; Fortus et al., 2005; Mehalik et al., 2008; Silk et al., 2009). A design-based unit may allow students to continuously externalize and test their mental models, which provides more opportunities to incorporate new information to their cognitive structures or in some cases develop new relationships between ideas.

One purpose of this study was to examine students' mental models following the completion of either an engineering design task or traditional learning activities as a culminating activity to a science unit. Since students from both the control and treatment group held similar conceptions, educators may question if incorporating engineering design is worth the additional time and effort it requires (Dankenbring, Rupp, and Capobianco, 2013). Due to the design of this study, it cannot be concluded that the mental models identified are the result of completing, or not completing, an engineering

design task; rather engineering design provided a context for students to apply their scientific understanding. It is worth emphasizing that the use of engineering design as a final activity did not hinder students' learning, but may have helped students that originally lagged behind their peers in terms of content knowledge, end on an even playing field. Also, engineering design has been shown to increase students' interest and awareness towards engineering and technology, enhance students' use of science vocabulary and teamwork skills, and increase students engagement in science lessons (Alfaro, Barbosa, Ishola, Gorman, Marquex, & Mooney, 2003; Barnett, 2005; Ortiz, 2008; Redmond, Thomas, High, Scott, Jordan, & Dockers, 2011; Roth, 1996, 1997). Engineering design also has the potential to increase students' attitudes towards science and improve students' problem solving skills (Ferreira & Trudel, 2012; Ornstein, 2006). Therefore, to determine the effects of integrating engineering design into the K-12 curriculum, more research is necessary, however this study provided implications for researchers, science teachers, teacher educators, and policymakers, which are described below.

Implications

Many benefits of incorporating engineering design into the science classroom have been reported, yet more research is needed to determine *how* engineering design impacts student learning. Knowledge gained from this study indicated the need for research to address the following questions:

- To what extent can engineering design facilitate conceptual change?
- In what ways does the placement, or use, of an engineering design task influence students' mental models?
- To what extent does the nature of a design task impact student' mental models?

This study demonstrated the wide range of ideas students' have regarding the amount of daylight the United States experiences throughout the year after completing a unit on sun-Earth relationships. In order to foster more meaningful connections within mental models, teachers need to identify students' preconceptions prior to instruction (Vosniadou & Ioannides, 1998). The use of various instructional strategies coupled with lessons that specifically target common misconceptions can be an effective tool in reducing the number of alternate conceptions students have (Bakas & Mikropoulos, 2003; Chiras & Valanides, 2008; Diakidoy & Kendeou, 2001; Küçüközer, Korkusuz, Küçüközer, & Yürümezoğlu, 2009; Vosniadou, 1991). Teachers also need to utilize various forms of formative and summative assessments to identify students' conceptions as they progress through and complete a unit. Examining students' mental models through the use of a draw-and-explain item can serve as an efficient and effective approach to ascertain students' science conceptual understanding.

The instructional choices made by teachers as they implement engineering practices in the classroom can influence student learning, thus it is imperative that in-service and pre-service teachers receive training in this arena. Professional development that familiarizes in-service teachers with the engineering design process will increase teachers' content knowledge, which will translate into more informed classroom practices (Abell, 2007). By participating in design-based curriculum, teachers gain firsthand knowledge of how their students will experience engineering design tasks as well as the challenges and benefits associated with engaging in engineering design (Dankenbring, Rupp, & Capobianco, 2013). However, exposure to engineering design tasks alone is not necessarily sufficient for teachers to be comfortable teaching design, thus professional

development should also focus on increasing teachers' pedagogical content knowledge about how to use design-based pedagogies for science learning (Capobianco, 2011; Magnusson, Krajcik, & Borko, 1999). Similarly, teacher education programs should provide pre-service teachers knowledge and experience with the engineering design process and how to utilize engineering design tasks in their classroom.

The *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) and *Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas* (NRC, 2012) advocate the integration of engineering practices into the science curriculum as a way for students to apply their scientific understandings. However, the NGSS offer no suggestions for incorporating these practices such that students will best learn the science content. Thus, policymakers and science educators can use the findings of this study to determine how best to utilize engineering design in the science curriculum. It appears that engineering design tasks as a culminating activity may be insufficient for enhanced science learning; rather, students may need prolonged exposure to multiple iterations of the design process to effectively alter their mental models.

Limitations of the Study

There are several limitations to consider in this study. The first limitation includes the size of the study sample. This study includes approximately sixty fifth grade students from four classrooms in one school. Findings from this study may be more generalizable if the study sample was larger and more diverse. One way to address this limitation may be to include teachers and students from more schools and different school communities. However, the focus of this study was to obtain a detailed description of students' mental models, and therefore, attention must be given to the complex nature of students' ideas. A

small sample size enables the researcher the time and effort required to acquire and verify students' mental models through open response items and individual student interviews.

A second limitation is exposure to engineering design. Only recently have reform documents made the call for the integration of engineering principles into the elementary science classroom. Teachers and students alike may have limited opportunity to learn about the engineering design process and engage in engineering principles. Attention has been given to enhance teachers' understanding and knowledge of engineering design, how to design engineering-design based curricula, and implementation of available engineering curricula (Capobianco, Diefes-Deux, & Mena, 2011; Cunningham, 2008; McGrath, McKay, & Shultz, 2008). Collectively, these studies suggest that elementary teachers' familiarity with engineering design largely influences students' ability to effectively engage in the engineering design process. Therefore, prolonged engagement in and exposure to engineering design is critical to effectively foster students' understanding of the relationship between science learning and design.

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